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Strength of Steel Concrete Floor Slabs

Civil Engineering
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STRENGTH

OF

STEEL CONCRETE FLOOR SLABS

BY

ERNEST BEAR

THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

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This is to certify that the thesis prepared under the supervision of Professor Talbot by ERNEST BEAR, entitled STRENGTH OF STEEL-CONCRETE FLOOR SLABS, is approved by me as fulfilling this part of the requirements for the Degree of Bachelor of Science in Civil Engineering.

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STRENGTH OF STEEL CONCRETE FLOOR SLABS.

The tensile strength of concrete is much smaller than its compressive strength. A concrete beam in flexure will fail by tension in the concrete. Any method by which this tensile strength can be increased, or by which the tension can be taken by some stronger material, will increase the load-carrying capacity of the beam, so long as the resisting strength for compression is equal to or greater than that for tension.

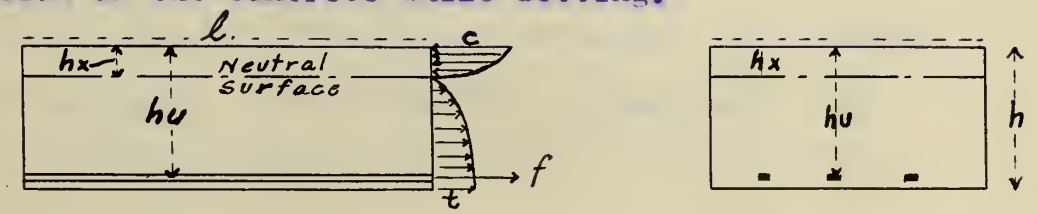
The growing tendency to use concrete construction in buildings has made it necessary to find some means of obtaining long spans, and, at the same time, of securing economy in weight and cost, as well as safe construction. With this in view, several methods have been devised to reinforce the tension flange of the concrete beam by the use of metal. Sometimes steel rods are imbedded in the lower flange of the beam for this purpose. These rods are usually straight, but occasionally are twisted or bent in order to increase the adhesion between the steel and concrete. Expanded metal, which will be described later, is also used for reinforcing the concrete. Another method, which was used in constructing the floor of the Hydraulic Laboratory at the University of Illinois, consists in imbedding ordinary wire netting in the tension flange of the concrete.

The purpose of these experiments is to make a comparison of strengths of the plain concrete and reinforced slabs, and also a comparison between those beams reinforced with expanded metal, and those reinforced with one or two layers of wire netting. It is also intended to compare the strengths of slabs reinforced with the same kind and amount of metal placed at different depths. The stresses in the concrete and metal will be computed at important changes in the condition of the loaded slab.

CONSIDERATION OF THEORIES.

Hatt's Theory.

Various theories are advanced to show the relation between the concrete and its reinforcement. Perhaps the best known analysis is that of Professor W. K. Hatt of Purdue University. He bases the theory upon the following assumptions:- (1) the cross-sections of the beam remain plane surfaces after bending; (2) the applied forces are perpendicular to the neutral surface of the beam; (3) the values of the moduli of elasticity, obtained in simple tensile and compressive tests, will apply to the material when under stress in the beams; (4) there is no slipping between the concrete and reinforcement; (5) there are no initial stresses in the beam due to shrinkage or contraction of the concrete while setting.



The variation of stress assumed is as shown in the figure. The stress diagrams are assumed to be parabolic arcs.

The following nomenclature will be used.

l = length of span. b = width of cross-section.

h = depth of cross-section.

hx = distance from compressive face to neutral surface.

hu = distance from compressive face to center of gravity of reinforcement. p = ratio of area of steel to cross-section of beam.

Es, Ec, Et = coefficients of elasticity of steel, concrete in compression, and concrete in tension.

Es = 29,000,000. Ec = 2,000,000. Et = 1,000,000.

$n = \frac{Ec}{Et} = 2$. $m = \frac{Es}{Et} = 29$.

f = unit-stress in reinforcement.

c = compressive unit-stress in concrete.

t = tensile unit-stress in concrete.

From the assumption that plane cross-sections remain plane sections during flexure, we have;

$c = \frac{tnx}{1-x}$, $t = \frac{f(1-x)}{m(u-x)}$, $c = \frac{fnx}{m(u-x)}$.

Equating the forces of tension and compression we have;

$2/3cx = 2/3t(1-x) + pf$. By substituting the values of c and f, we have;

$2/3x^2 n = 2/3(1-x)^2 + pm(u-x)$. Solving for x we obtain;

$$x = \frac{-\left(\frac{4 + 3pm}{2}\right) + \sqrt{4n + 9/4p^2m^2 + p\left[6m\left(u\left[n-1\right] + 1\right)\right]}}{2(n-1)},$$

$$\frac{1-x}{\text{etc.}} \cdot \quad \frac{\text{[illegible]}}{\text{[illegible]}} \cdot \quad \frac{\text{etc.}}{\text{etc.}} \cdot$$

Taking moments about the neutral axis we have;

$M = bh^2 \left[2/5t(1-x)^2 + 2/5cx^2 + pf(u-x) \right]$

When the beam has cracked the effect of tension must be omitted. Equating the tensile and compressive forces, we have;

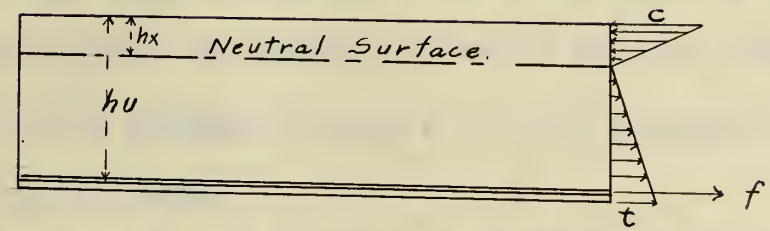
$2/3cx = pf$ or, $x^2 = 3/2p\frac{Es}{Ec}(u-x)$. The bending moment then is

$M = bh^2 \left[2/5cx^2 + pf(u-x) \right]$.

There seems to be inconsistency among the assumptions in that a parabolic stress diagram is taken with uniform coefficients of elasticity and a straight line deformation.

COMMON THEORY OF BEAMS.

A modification of the common theory of beams will apply to reinforced beams. The same assumptions are made as in the preceding analysis.



The stress-strain diagrams are assumed to be straight lines instead of arcs of parabolas. Assuming that plane sections remain plane sections after bending we have;

$c = \frac{tnx}{(1-x)}$, $t = \frac{f(1-x)}{m(u-x)}$, $c = \frac{fnx}{m(u-x)}$.

Equating the tensile and compressive forces we obtain;

$1/2cx = 1/2t(1-x) + pf$. Substituting the values of c and f we have;

$x^2 + 4\left(\frac{1\ pm}{2n-1}\right)x = \frac{2 + 4pmu}{2n-1}$ from which x can be obtained.

Taking moments about the neutral axis the following equation is

obtained;

$M = bh^2 \left[1/3t(1-x)^2 + 1/3cx^2 + pf(u-x)\right]$

When the beam has cracked, tension of the concrete can not be considered. Equating the tensile and compressive forces we have; $x^2 = 2p \frac{Es}{Ec}(u-x)$, from which the position of the neutral surface can be found, Taking moments about the neutral surface we have;

$M = bh^2 \left[1/3cx + pf(u-x)\right]$

It is found that this modification of the common theory of beams gives results that agree very closely with Professor Hatt's analysis, as well as with experiment.

OTHER THEORIES.

Mr. A. L Johnson has lately worked out a theory that seems rational. It is published in pamphlet form by the St. Louis Expanded Metal Company of St. Louis, Missouri. It was received too late however to be discussed here.

Professor Wakin of the Massachuetts Institute of Technology has also derived some formulas to be used in designing concrete-steel beams, but they do not seem applicable to the slabs bere considered.

DESCRIPTION OF TEST PIECES.

SIZE. Twenty six slabs of concrete were made for these experiments. Each slab was 4 feet 6 inches long, 18 inches wide, and 4 inches thick. By placing the supports 3 inches from each end a span of 4 feet was obtained, which is a common length of span in floor construction. Although narrower than the sections of a concrete floor, the slabs will act similar to those sections under loading.

CEMENT. The Owl brand of Portland cement, made by the German American Portland Cement Company, was used. Five briquettes of neat cement developed an average tensile strength of 515 pounds per sq. in. in seven days, and five developed a strength of 715 pounds per sq. in. in thirty days.

SAND. Ordinary bank run sand from Urbana, Illinois, locally known as gravel, was used. It contained 38 per cent of voids, and would be classed as coarse sand. Briquettes of cement and sand, made in the proportion of one part of cement to three of sand, broke at a tensile stress of 190 pounds per sq. in. when seven days old, and at 305 pounds per sq. in. when thirty days old. The average of five briquettes was taken in each case.

STONE. The stone used was Kankakee limestone from Kankakee, Illinois. It contained 58 per cent voids. The sizes of the stones ranged from 1/8 inch to 1 1/2 inch in longest dimension.

CONSTRUCTION OF SOME MISSING.

CONCRETE. The concrete was mixed in the proportion of one part of cement to 3 of sand to 6 of stone. An amount of water equaling 14 per cent of the aggregate was used, making a moderately wet concrete. The proportions were made by measurement of volume. The concrete was mixed by hand.

MORTAR. A coating of 1 to 3 mortar 1/4 inch thick was placed at the top of each test piece, and was made a plane surface as nearly as possible by the use of a straight-edge and trowel. A coating of mortar 1/4 or 1/2 inch thick (depending on the kind of test piece) was placed at the bottom of each slab. The sand for this mortar was obtained by screening the bank-run sand with a number 4 sieve.

METAL REINFORCEMENTS. Expanded metal and wire netting were used for reinforcing the concrete. Expanded metal is made by cutting short, parallel slits about 1/4 inch apart in thin, sheet steel, and then pulling these slits into meshes. The size of mesh was 3 inches on a side. The average of several tests showed that the ultimate tensile strength of this metal was 55000 pounds per sq. in. Each strip was .072 inches thick and .26 inches wide. The amount of metal per inch of width of test piece was .016 sq. in. The wire netting was ordinary netting used for fences. The following figure shows the way in which the meshes were formed.

Each mesh was about 1 1/4 inches on a side. An average of several tests gave an ultimate tensile strength of 60,000 pounds per sq. in. The wire was .075 inches in diameter. The amount of metal per inch of width of test piece was .0061 sq. in.

MAKING THE TEST PIECES. The test pieces were made of the same kind of concrete, and with practically the same amount of tamping. Since it would take several days to make all the tests ~~pieces~~, one of each set was made each day, and from the same batch of concrete. The object of this was to give those slabs made on the same day the same amount of care and consideration, thereby eliminating accidental errors and daily variations in the quality of mixing and tamping. When this is done a closer comparison of the strengths of the various kinds of test pieces is made possible.

STORING THE TEST PIECES. After the test pieces were made they were left in a dry room which was kept at a temperature of about 60 degrees, Fahr. Each day they were thoroughly wet in order to secure proper conditions for setting. The pieces were broken after 60 days.

CLASSIFICATION OF TEST PIECES. The test-pieces were divided into seven sets, according to the kind, amount and position of the reinforcement, as follows:-

SET NO. 1. PLAIN CONCRETE SLABS.

SET NO. 2. SINGLE NETTING SLABS. One layer of wire netting was placed 3/8 inch from the bottom.

SET NO. 3. DOUBLE NETTING SLABS. Two layers of wire netting were

placed 3/8 inch from the bottom.

SET NO. 4. EXPANDED METAL SLABS. Expanded metal was placed 3/8 inch from the bottom.

SET NO. 5. SINGLE NETTING SLABS. One layer of netting was placed one inch from the bottom.

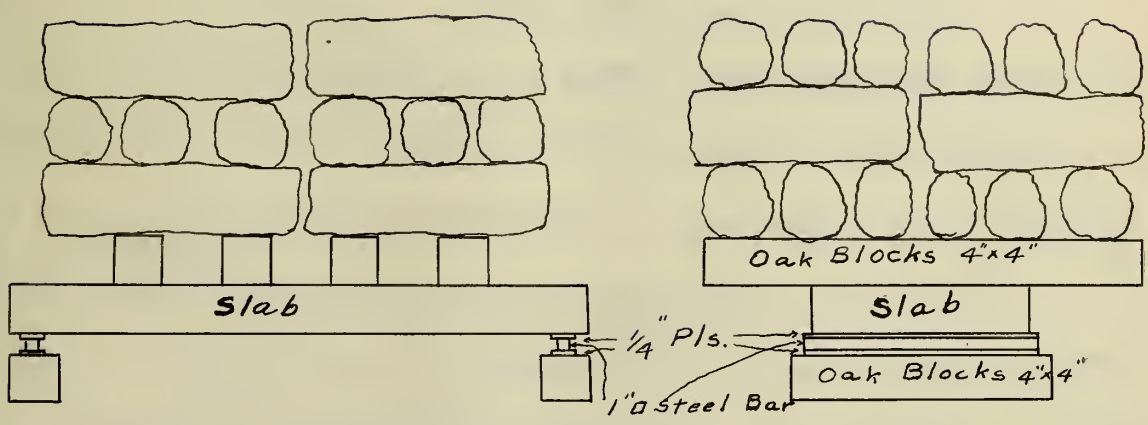
SET NO. 6. DOUBLE NETTING SLABS. Two layers of netting were placed one inch from the bottom.

SET NO. 7. EXPANDED METAL SLABS. Expanded metal was placed one inch from the bottom.

The reinforcement was imbedded in the mortar in sets No. 2, 3 and 4, but in the concrete in sets No. 5, 6 and 7.

METHOD OF TESTING.

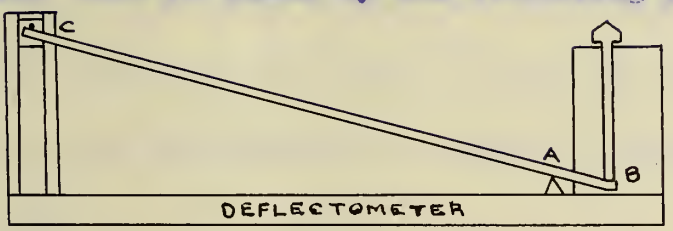
The arrangement, shown in the following figure, was used in breaking the slabs.



wooden blocks 4 inches square were placed 4 feet apart on a concrete floor. These pieces supported two 1/4-inch steel plates with a one

inch square steel bar between them. The test piece was placed upon these supports, thus giving a space of 5 1/2 inches between the floor and slab. This afforded sufficient room for a deflectometer, which was placed so that the point of contact of the test piece and deflectometer came as near as possible to the center of gravity of the bottom surface of the test piece. Oak blocks 4 inches square and 3 feet long were placed across the test-piece at four different points, dividing the span into five equal parts. Pig iron was piled upon the oak piece for breaking the concrete slab. Before any slabs were broken each pig was weighed and marked, so that it was an easy matter to calculate the load on the slab at any time.

Deflections were read at every additional 200 pound load. The type of deflectometer used is shown by the following figure.



The shorter arm AB is 1 1/2 inches long, and the other arm AC is 15 inches long. Therefore any motion at B is ten times as great at C. Deflections were read to thousandths of an inch by means of a vernier attached to the pointer.

It was desired that the test-pieces be broken with the load as nearly uniformly distributed as possible. The method of loading previously described produces a maximum bending moment expressed by the formula $M = 3/20\ Wl$, in which W is the total load in pounds, and l is the span in inches. The maximum bending moment due to a uniform

load is expressed by the formula M = 1/8 Wl, which is seen to be very close to the other. The elastic curve and the distribution of the shear are also quite similar to those for beams uniformly loaded.

A more important purpose in choosing this loading was to avoid the effect of the arching action of the load, due to the deflection of the test-piece. Several investigators have entirely neglected to consider this arching action in their experiments, while others have given it more or less attention. Since the amount of the load, the height of the load, the deflection of the slab, and the shape and nature of the weights determines the amount of the arching action for each method of uniform loading, it is seen to be a variable and indeterminate quantity for each test-piece. If the amount of this arching action is unknown, the effective load and its distribution is also unknown, and the weight on the beam can only be estimated.

The method of loading used eliminates the arching action and obtains a nearly uniform load.

RESULTS OF TESTS.

TABLE NO. 1.

Showing Breaking Loads for Each Test-piece.

SET NO.	KIND OF TEST-PIECE	NO. OF SLAB	CRACKING LOAD IN LBS.	TOTAL BREAKING LOAD. LBS.	BREAKING LOAD. LBS. PER SQ.FT.
1	PLAIN CONCRETE	1	1465	1465	244
		4	1545	1545	257
		15	1840	1840	307
		22	2250	2250	375
2	SINGLE NETTING	2	2500	2810	468
		10	2135	2135	356
		17	1935	2160	360
		23	2725	2725	454
3	DOUBLE NETTING	3	4065	5875	979
		11	3880	4770	795
		16	4075	4475	746
		24	4550	4720	787
4	EXPANDED METAL	5	3700	4580	763
		9	3185	6180	1030
		18	3220	5975	996
		25	4040	6485	1081
5	SINGLE NETTING 1" from bottom.	7	1820	1820	303
		14	1960	1960	353
		19	2325	2325	388
6	DOUBLE NETTING 1" from bottom	8	1560	1740	290
		13	2010	2075	346
		20	2630	2630	438
7	EXPANDED METAL 1" from bottom.	6	2460	4875	812
		12	2565	3395	566
		21	2720	4965	827
		26	2485	4220	703

From the table it will be seen that the plain concrete slabs were nearly as strong as those containing one and two layers of wire netting one inch from the bottom. Those test-pieces in which the single netting was one inch from the bottom were not materially

strengthened by the metal, because this reinforcement was too near the neutral surface to take any appreciable amount of tension before the concrete had failed in tension, and then the amount of metal was too small to take the tension suddenly applied. By placing the metal as near the bottom as possible, it is stressed more gradually, and there is a better chance to distribute the tension over the concrete, in addition to the advantage in the increased resisting moment of the metal.

The metal in those slabs having two layers of netting one inch from the bottom was not very efficient. As in the preceding case, the metal had taken but little stress before the concrete failed in tension. Then too, the bond between the concrete on each side of the reinforcement was poor, because the meshes were too close together to allow the stones to work through, and form good contact during the tamping. As a result all the concrete below the reinforcement scaled off when the beam was loaded.

These two cases suggest the following precautions to be taken in floor construction:- the reinforcing metal should be placed as near the bottom of the slab as possible; the metal should be firmly imbedded in mortar, in order to transmit the tension over as much of the concrete as possible; the meshes of the reinforcement should not be so small that the bond of the concrete is impaired.

Before computations were made, it was necessary to know the coefficient of elasticity of the concrete. Two blocks of concrete 6 inches wide, 4 inches thick, and 18 inches long were cut from the

ends of two plain concrete test-pieces. The ends were taken with the idea that the concrete was not materially stressed at this section when the slabs were broken. Extensometers, reading to .0001 inch, were fastened firmly to each side of the blocks. The maximum compression applied was 350 pounds per sq. in., which was not great enough to cause a permanent distortion of the concrete. Deformations were read at each addition of 1000 pounds to the load. The results were plotted and gave an average value of 2,000,000 for the coefficient of elasticity in compression. The results were not uniform, and on that account not very satisfactory. Professor Hatt found that the coefficient of elasticity in compression was about twice that in tension, and it will be so considered in this discussion.

The pieces used for finding the coefficient of elasticity were afterwards broken. They failed at a compressive stress of 1800 pounds per sq. in.

COMPUTATIONS.

In the discussion previously given, Professor Hatt shows that the position of the neutral surface of reinforced concrete slabs is given by the following formula;

$$x = -\left(\frac{4 + 3pm}{2}\right) + \frac{\sqrt{4n + 9/4\ p^2\ m^2 + p\left[6m(u\,[n-1] + 1)\right]}}{2(n-1)}$$

h = depth of slab = 4 inches.

hx = distance from top of slab to neutral surface in inches.

$p = \frac{\text{area of cross-section of metal}}{\text{area of cross-section of concrete}}$,

Es = coefficient of elasticity of steel = 29,000,000.

Ec = Coefficient of elasticity of concrete in compression = 2,000,000.

Et = Coefficient of elasticity of concrete in tension = 1,000,000.

$m = \frac{Es}{Et} = 29$.

$n = \frac{Ec}{Et} = 2$.

hu = distance from top of slab to center of gravity of reinforcement.

EXPANDED METAL SLABS. u = .91 p = .004. x = .443

DOUBLE NETTING SLABS. u = .91 p = .003 x = .436

SINGLE NETTING SLABS. u = .91 p = .0015 x = .426

PLAIN CONCRETE SLABS. u = 0 p = 0 x = .410

EXPANDED METAL SLABS. (one inch from bottom) u = .75 x = .436

After the first crack has appeared the concrete has failed in tension, and the following formula gives the position of the neutral surface.

$x^2 = 3/2p \frac{Es}{Ec} (u-x)$, $\frac{Es}{Ec} = 14.5$

EXPANDED METAL SLABS. u = .91 p = .004 x = .328

DOUBLE NETTING SLABS. u = .91 p = .003 x = .279

SINGLE NETTING SLABS. u = .91 p = .0015 x = .189

EXPANDED METAL. (one inch from bottom) u = .75 x = .303

As previously shown the general equation for bending moment according to Professor Hatt's analysis is ;

$M = bh^2 \left[2/5\ t\ (1-x)^2 + 2/5\ cx^2 + pf\ (u-x) \right]$ (1)

$$\frac{dy}{dx} \quad \frac{dx}{dy}$$

$c = \frac{tnx}{1-x}$, $t = \frac{f(1-x)}{m(u-x)}$, $c = \frac{fnx}{m(u-x)}$.

By substituting these values in (1), the following equations are obtained;

$$M = bh^2 t \left[2/5 (1-x)^2 + 2/5 \frac{nx^3}{1-x} + \frac{pm(u-x)^2}{1-x} \right] \quad (2).$$

$$M = bh^2 f \left[2/5 \frac{(1-x)^3}{m(u-x)} + 2/5 \frac{nx^3}{m(u-x)} + p(u-x) \right] \quad (3).$$

$$M = bh^2 c \left[2/5 \frac{(1-x)^3}{nx} + 2/5 x^2 + \frac{pm(u-x)^2}{nx} \right] \quad (4).$$

Not considering the tension in the concrete

$$M = bh^2 f \left[2/5 \frac{nx^3}{m(u-x)} + p(u-x) \right] \quad (5).$$

$$M = bh^2 c \left[2/5 x^2 + \frac{pm(u-x)^2}{nx} \right] \quad (6).$$

The position of the neutral surface by the Common Theory is given by the formula, using $\frac{Ec}{Et} = 2$;

$$x^2 + 4 \left(\frac{1 + pm}{2n - 1} \right) x = \frac{2 + 4 pmu}{2n - 1}.$$

EXPANDED METAL SLABS. $x = .424$

DOUBLE NETTING SLABS. $x = .414$

SINGLE NETTING SLABS. $x = .401$

PLAIN CONCRETE SLABS. $x = .387$

EXPANDED METAL SLABS. (one inch from bottom) $x = .414$

If the beam has cracked and tension in the concrete is not considered, the following formula gives the position of the neutral surface.

$$x^2 = 2p \frac{Es}{Ec} (u-x).$$

EXPANDED METAL SLABS. $x = .388$

DOUBLE NETTING SLABS. $x = .328$

SINGLE NETTING SLABS. $x = .222$

EXPANDED METAL SLABS. (one inch from bottom) $x = .358$

As previously shown the general equation for the bending moment is;

$$M = bh^2 \left[1/3\ t\ (1-x)^2 + 1/3\ cx^2 + pf\ (u-x) \right] \qquad (7).$$

Substituting the values of c, t and f as before, we have;

$$M = bh^2\ t \left[1/3\ \frac{(1-x)^2}{} + pm\ \frac{(u-x)^2}{(1-x)} + 1/3\ \frac{nx^3}{(1-x)} \right] (8).$$

$$M = bh^2 f \left[\frac{1/3\ (1-x)^3}{m(u-x)} + \frac{1/3\ nx^3}{m(u-x)} + p(u-x) \right] (9).$$

$$M = bh^2 c \left[\frac{1/3\ (1-x)^3}{nx} + 1/3\ x^2 + \frac{pm\ (u-x)^2}{nx} \right] (10).$$

Not considering tension.

$$M = bh^2 f \left[\frac{1/3\ nx^3}{m(u-x)} + p\ (u-x) \right] \qquad (11).$$

$$M = bh^2\ c \left[1/3\ x^2 + \frac{pm\ (u-x)^2}{nx} \right] \qquad (12).$$

As previously shown the bending moment equals 3/20 Wl. The values of c, f and t as given in the following tables were obtained by equating the moments, and substituting the values for x, u and W.

The value of f in the formulas is the amount of unit-stress in the wire in a longitudinal direction. Since the sides of the meshes of the reinforcement are inclined to the longitudinal axis of the slab, the area of the cross-section of the wire is equal to the normal cross section multiplied by the secant of the angle of inclination. The longitudinal stress in the wire is the component of the stress along the wire. Therefore the actual stress in the wire is equal to the longitudinal stress multiplied by the

secant of the angle of inclination. The values of f' given in the tables are then the actual unit-stress in the wire.

TABLE II.

SHOWING UNIT-STRESSES AT POINT A.

SET NO.	KIND OF TEST-PIECE.	NO.	x.	LOAD AT POINT A.	HATT'S THEORY			COMMON THEORY			
					c.	f.	t.	x	c.	f.	t.
4	EXPANDED METAL	5	.443	2400	330	7425	204	.424	360	9000	240
		9		2400	330	7425	204		360	9000	240
		18		2400	330	7425	204		360	9000	240
		25		1600	220	4950	136		240	6000	160
3	DOUBLE NETTING	3	.436	2800	390	9165	251	.414	370	11055	300
		11		2400	330	7860	215		315	9480	260
		16		2600	360	8550	233		345	10260	280
		24		3000	410	9825	268		395	11835	325
2	SINGLE NETTING	2	.426	Point A was not determined for this piece.				.401			
		10		1800	260	6435	175		265	7950	210
		17		1700	245	6075	165		250	7500	200
		23		2300	330	8335	225		340	10140	270
1	PLAIN CONCRETE	1	.410	1465 x	218	0	157	.387	245	0	195
		4		1545 x	231		166		260		205
		22		2250 x	337		242		375		300
7	EXPANDED METAL (1" from bottom)	6	.436	1800	270	4110	170	.414	295	5190	205
		12		1100	165	2550	110		180	3165	125
		21		2000	300	4575	190		320	5760	230
		26		2000	300	4575	190		320	5760	230

x Also breaking loads.

TABLE III.

SHOWING UNIT-STRESSES AT TIME OF RUPTURE.

SET NO.	KIND OF TEST-PIECE.	NO.	BREAKING LOAD LBS.	HATT'S FORMULA				COMMON THEORY.			
				x.	c.	f.	t.	x.	c.	f.	t.
4	EXPANDED METAL	5	4580	.328	1110	42900	0	.388	1260	36950	0
		9	6180		1500	57930			1700	49845	
		18	5975		1450	56020			1640	48195	
		25	6485		1580	60795			1780	52320	
3	DOUBLE NETTING	3	5875	.279	1580	77290	0	.328	1820	64945	0
		11	4770		1280	62760			1480	56790	
		16	4475		1200	58875			1380	53265	
		24	4720		1270	62100			1460	56190	
2	SINGLE NETTING	2	2810	.189	950	78060	0	.222	1120	75600	0
		10	2135		720	59310			850	57600	
		17	2160		730	60000			860	58275	
		23	2725		930				1090	73515	
1	PLAIN CONCRETE	1	1465 *	.410	218	0	157	.387	245	0	195
		4	1545 *		231		166		260		205
		15	1840 *		275		198		310		245
		22	2250 *		337		242		375		300
7	EXPANDED METAL (1" from bottom)	6	4875	.303	1110	52230	0	.358	1800	42765	0
		12	3395		770	36375			1260	29700	
		21	4965		1120	53195			1840	43560	
		26	4220		960	45200			1560	37000	

* Also load at Point A.

The values of the load at Point A are taken from the diagrams on following pages. The point A is the place at which the load-deflection diagram departs from a straight line (see diagrams) This point indicates some change in the condition of the loaded test-piece, probably the failure of the concrete in tension.

TABLE NO. IV.

Showing Relative Strengths of Reinforced and Plain Concrete Slabs at Time of Rupture.

SET NO.	KIND OF SLAB.	AVERAGE BREAKING LOAD IN POUNDS.	BREAKING LOAD, POUNDS PER SQ. FT.	PER CENT OF STRENGTH OF PLAIN CONCRETE SLABS.
1	PLAIN CONCRETE.	1750	292	100
2	SINGLE NETTING.	2450	408	140
3	DOUBLE NETTING.	4960	827	280
4	EXPANDED METAL.	5800	967	330
7	EXPANDED METAL (1" from bottom).	4360	728	250

TABLE NO. V.

Showing Relative Strengths at appearance of First Crack.

SET NO.	KIND OF SLAB.	AVERAGE BREAKING LOAD IN POUNDS.	BREAKING LOAD, POUNDS PER SQ. FT.	PERCENT OF STRENGTH OF PLAIN CONCRETE SLABS.
1	PLAIN CONCRETE.	1750	292	100
2	SINGLE NETTING.	2325	387	130
3	DOUBLE NETTING.	4140	690	240
4	EXPANDED METAL.	3535	590	200
6	DOUBLE NETTING (1" from bottom)	2100	350	120
7	EXPANDED METAL (1" from bottom).	2555	426	150

CONCLUSIONS.

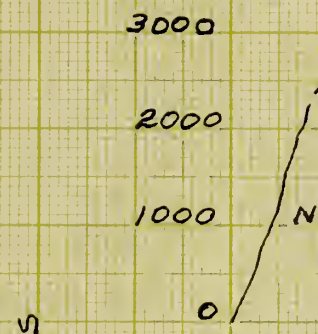
From table II it is seen that at the point A both the compressive unit-stress in the concrete and the tensile unit-stress in the metal are low, and the tensile unit-stress in the concrete is high, each as compared with its ultimate strength. This shows that the concrete is about to fail by tension, as was previously stated.

The tensile unit-stress in the plain concrete slabs is, in general, lower than that in slabs containing metal. This is probably due to the fact that the metal distributes the tension over the concrete more uniformly, and thus increases its ultimate tensile strength. The tensile strength of the concrete in the double netting slabs is greater than in those with single netting. This seems to indicate that the more uniformly the metal is arranged along the breadth of the slab, the better the tension is distributed through the concrete. The ultimate tensile strength of the concrete in set No. 7 is no higher than in set No. 1. The cause of this is that the metal is so near the neutral surface it has but little opportunity to distribute the tension through the concrete.

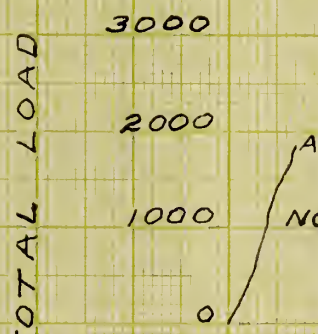
From table No. III, for breaking loads, it is seen that the metal probably breaks in set No. 4, although the compressive unit-stress of the concrete is very near the ultimate unit-stress. The metal breaks in sets No. 2, 3 and 7 as shown by the computations. The value of the compressive unit-stress becomes lower the smaller the amount of metal in the test-piece, showing that not enough

metal was used to develop the full compressive strength of the concrete. The stress in the metal is set No. 7 is low due in most part to the smaller resisting moment of the metal.

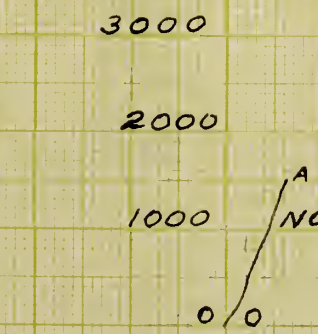
These experiments show that reinforced concrete slabs are much stronger than plain concrete slabs. The metal should be placed as near the bottom of the slab as possible, and yet be firmly imbedded in the concrete. The metal should be distributed across the breadth of the slab as uniformly as possible, but the meshes should not be so close together that the bond of the concrete is impaired. Enough metal should be used to develop the compressive strength of the concrete. Reinforced slabs give notice of approaching failure by cracking, and are still able to carry additional loads, while plain concrete slabs fail without warning.



LOAD-DEFLECTION DIAGRAMS FOR PLAIN CONCRETE SLABS.



TOTAL LOAD IN POUNDS



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DEFLECTIONS AT CENTER IN INCHES

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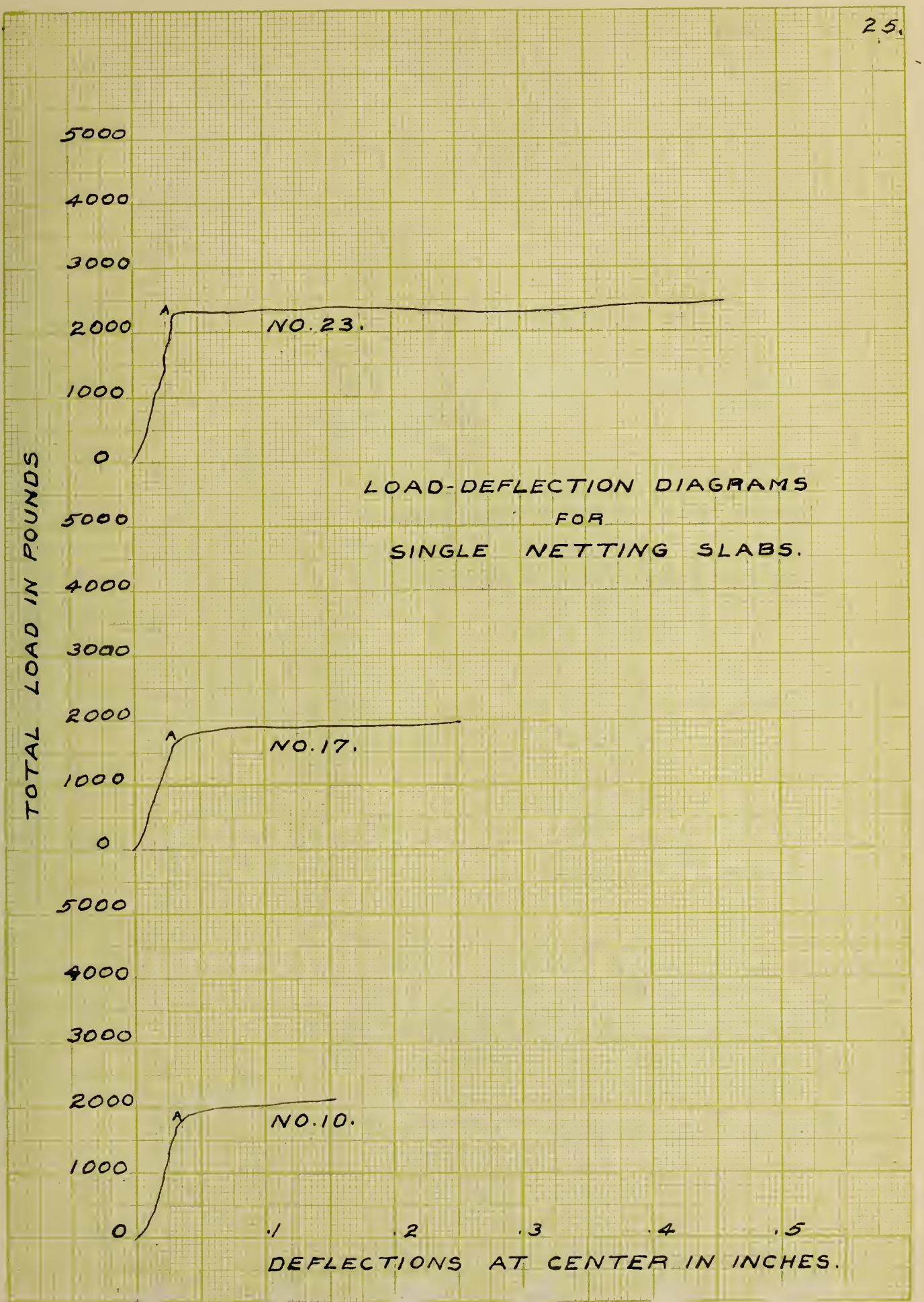

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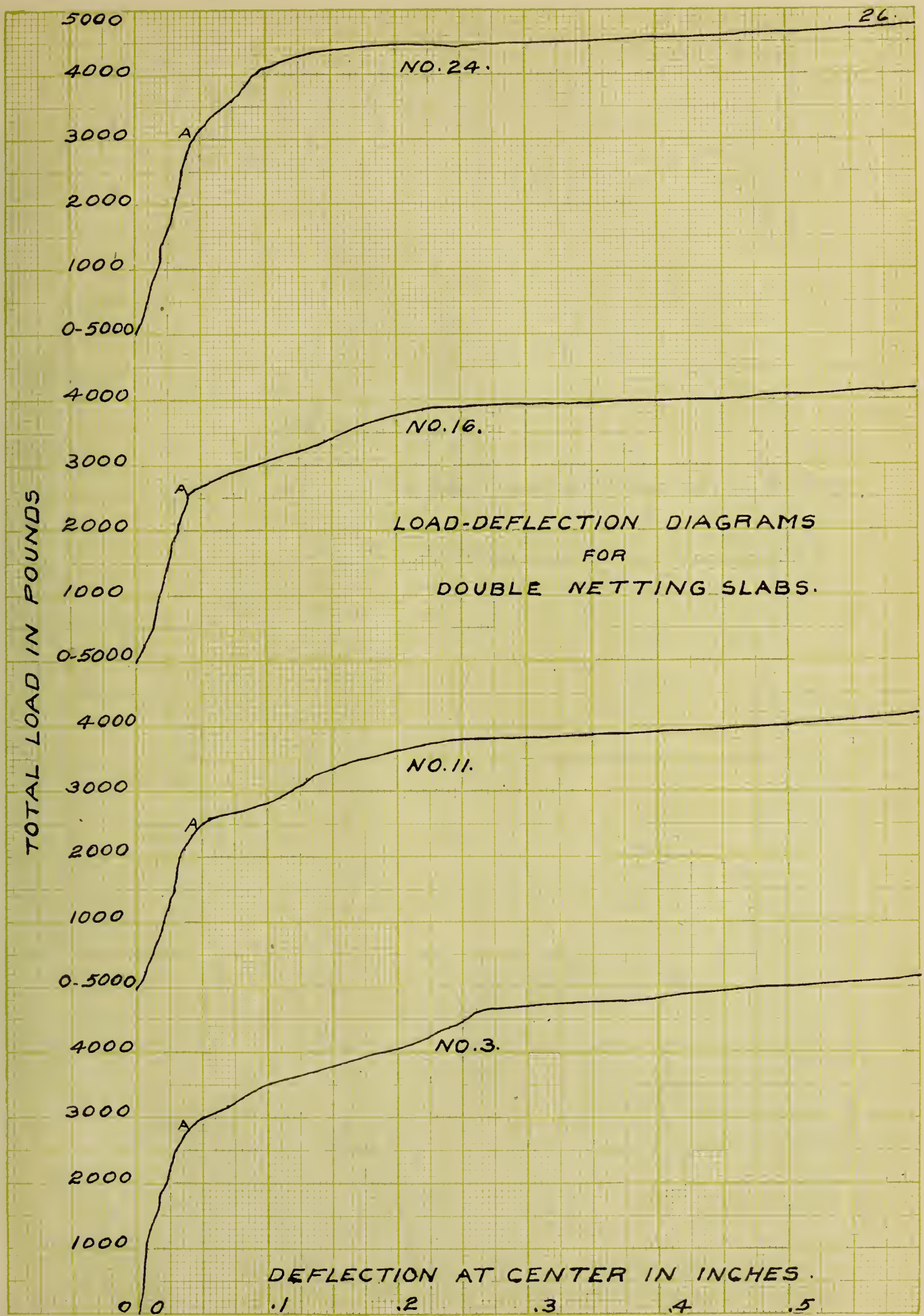

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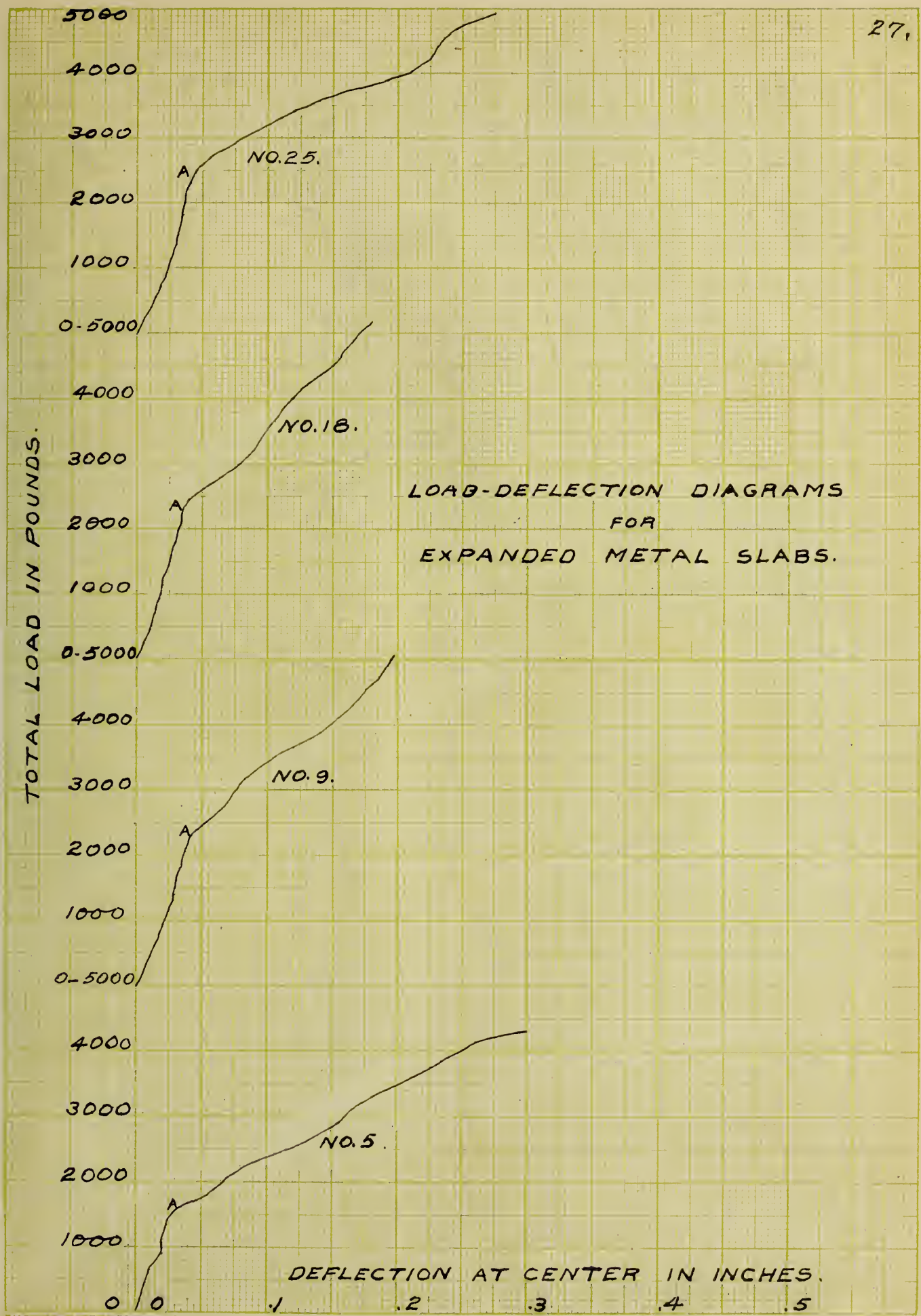

LOAD-DEFLECTION DIAGRAMS
FOR
EXPANDED METAL SLABS.

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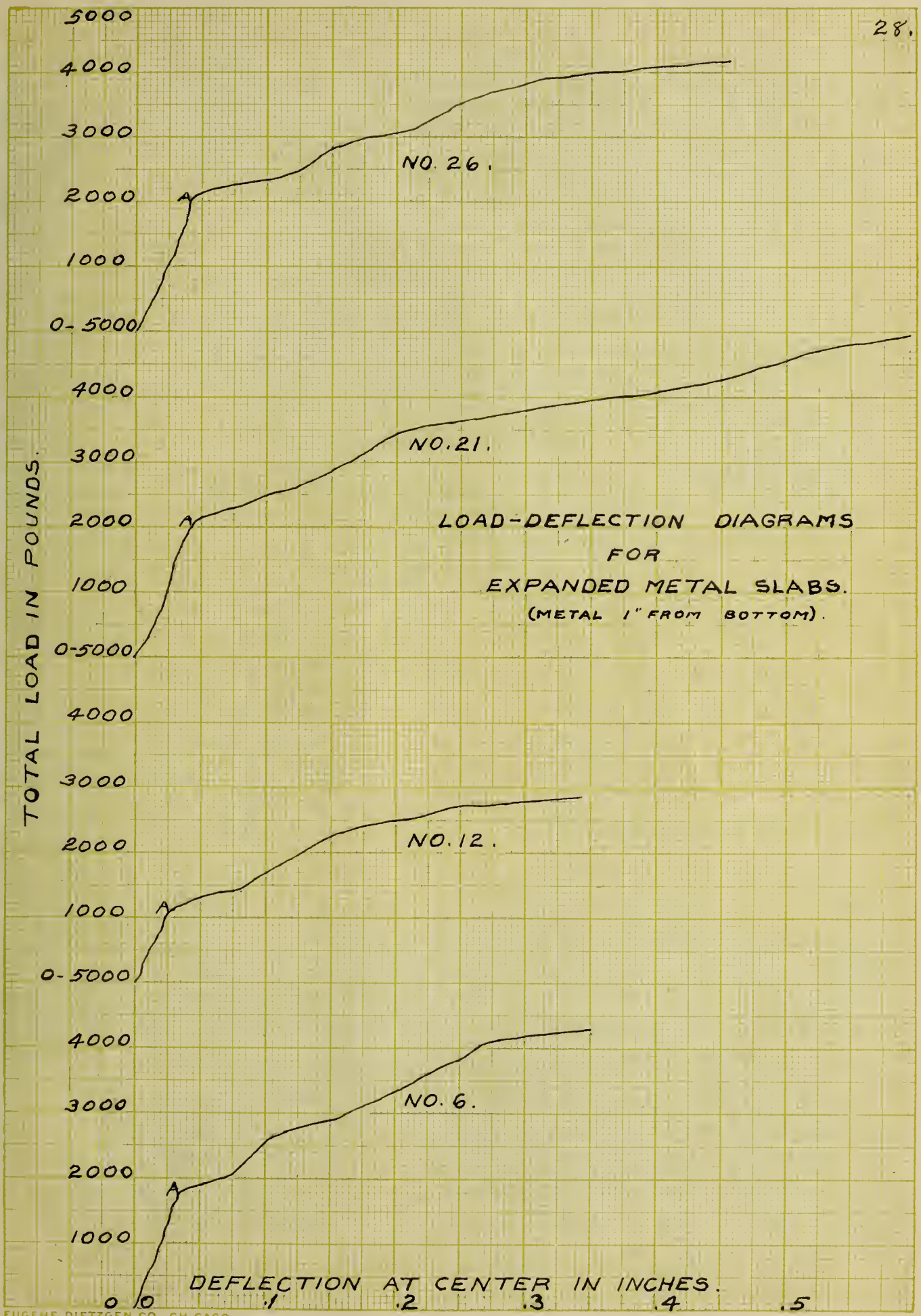

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